ICAE
Instituto Complutense de Análisis Económico
UNIVERSIDAD COMPLUTENSE
FACULTAD DE ECONOMICAS
Campus de Somosaguas
28223 MADRID

Teléfono 394 26 11 - FAX 294 26 13

Documento de trabajo

Testing the Expectations Hypothesis in Eurodeposits

Emilio Domínguez
Alfonso Novales

No.9806 Mayo 1997

ICAE
Instituto Complutense de Análisis Económico
UNIVERSIDAD COMPLUTENSE

TESTING THE EXPECTATIONS HYPOTHESIS IN EURODEPOSITS

Emilio Domínguez
Departamento de Fundamentos del Análisis Económico
Universidad Pública de Navarra
Pamplona. Spain.

Alfonso Novales
Departamento de Economía Cuantitativa
Universidad Complutense
Madrid. Spain.

ABSTRACT

Analyzing data on Euro-rates for 1978-1996, we find consistent evidence in favor of the Expectations Hypothesis *(EH)* of the term structure: a) interest rates offered on deposits in a given currency form a cointegrated system, b) the restrictions of the *EH* on the cointegrating relationships are not rejected, except at the longer maturities, c) forward rates contain significant explanatory power on future interest rates, unbiadsedness being an acceptable hypothesis, which d) can lead to good interest rate forecasts, specially at the shorter maturities.

***Keywords:** Expectations hypothesis, term structure, forward rates*
***JEL classification:** E37, E43*

1. INTRODUCTION

Characterizing the properties of the term structure in markets where a given asset is offered at different maturities is a central issue in financial economics, for a variety of sound reasons. Apart from its relevance for monetary policy implementation, or from the possible ability of the term structure slope to predict future changes in economic activity, it has been discussed for a number of years that some characteristics of the term structure contain significant information on future interest rate changes. Specifically, according to the *Expectations Hypothesis* (*EH*) of the term structure, long-term interest rates are an average of current and expected future short-term rates over the life of the investment. An implication is that there is a close link between short- and long-term rates, to the point that their spread contains all relevant information on future changes in short-term rates. That would be of utmost interest not only for policy makers, but also for market participants, which could otherwise hope to design profitable investment strategies using information currently available.

Interest rates on Eurodeposits, known as Euro-rates, provide an interesting data set on which to test these issues. They share important characteristics, not being distorted by differences in the fiscal treatment of returns or in the timing of interest payments, and not being affected by possible capital controls or other government regulations. That makes them more comparable than domestic rates, so testing the *EH* with Euro-rates should lead to fairly robust conclusions on the relationship between short- and long-term returns.

The ability of the *EH* to explain the behavior of interest rates over the term structure has been controversial for a long time. Even though the initial evidence on *US* data [Shiller, Campbell and Schoenholtz (1983), Fama (1984), Fama and Bliss (1987) and Shiller (1990)] consistently rejected the restrictions implied by the *EH*, some of these authors obtained evidence on the existence of explanatory power in the short/long-term interest rate spread on future short-term rates. Fama (1990) and Mishkin (1988) both found that the spread does contain information on short-term rates several periods into the future. Mankiw and Summers (1984) and Mankiw and Miron (1986) analyzed 3- and 6-month *US* rates, concluding that the term structure had important explanatory power for future interest rates, although it seems to have faltered after the founding of the Federal Reserve System. Campbell and Shiller (1987,1991) found again that the restrictions of the *EH* do not hold, but that the *US* spread explains the direction of changes in short-term rates. However, the predicted changes are small, suggesting a possible time varying risk or term premium. Similar results were obtained by

Jorion and Mishkin (1991).

Some evidence has recently been brought up in favor of the *EH*: Hardouvelis (1994) uses quarterly data from the *G-7* countries, and rates of return on three month and 10 year bonds, to conclude that the cumulative movements in future short term rates roughly agree with the implications of the theory, and strongly rejecting the hypothesis that the spread lacks any explanatory content. Even more recently, Gerlach and Smelts (1997) have obtained evidence in favor of both, the restrictions of the *EH*, and the explanatory power of the spread on future short-term rates. An additional result from Hardouvelis (1994) and Gerlach and Smelts (1997) is that the *EH* tends not to do very well in the *US* so that the hypothesis should tested with international data.

The goal of this paper is to test several implications of the *EH* in the market for Eurodeposits, using data on interest rates at 1-, 3-, 6- and 12-months, for the *US* dollar, Japanese yen, German mark, British pound, Spanish peseta, French franc, Italian lira and Swiss franc, between January 1978 and December 1996. We first test whether there is a tight connection between short- and long-term rates over a given term structure. Given their non-stationary nature at all the different maturities and for all currencies considered, we view the vector of returns offered in a given currency as a system of possibly cointegrated variables, and estimate and interpret the number of cointegrating relationships between them. After that, we proceed to analyze the information content in the long/short-term spread on future short-term interest rate fluctuations. In particular, we pay special attention to test whether forward rates are unbiased predictors of short-term rates. To do so, we again take into account the non-stationary nature of forward rates, and look at possible cointegrating relationships between forward rates and the corresponding future short-term spot rate. Our estimation and testing results are quite favorable to the *EH*.

After providing such evidence, we analyze whether the restrictions that the *EH* imposes on the behavior of returns over the term structure can in fact be used to produce improved short-term interest rate forecasts. To that end, we evaluate the extent to which the explanatory power detected in forward rates can be used to produce sensible forecasts of future short-term interest rates. In spite of the forecasting connotation of the unbiasedness property of forward rates, actual evaluation of the forecasting performance of forward rates has received scant attention in the literature on the term structure, may be due to skepticism on its possibilities. To the best of our knowledge, this is the first systematic attempt to measure the actual predictive power of the term structure under the restrictions of the Expectations Hypothesis on international data.

In Section 2 we review some concepts relating to the *EH*, and analyze the term structure as a system of possibly cointegrated set of rates of return. In Section 3 we characterize the information content in implicit forward rates on future short-term rates and test for unbiasedness. Whether the explanatory power in forward rates can be used to produce good forecasts of short-term rates is discussed in Section 4. The paper closes with some conclusions.

2. THE TERM STRUCTURE AS A COINTEGRATED SYSTEM OF RATES OF RETURN.

According to the *EH*, the return on an n-period investment, r_t^n, should be equal to the average expected return on a roll-over strategy over that period, plus possibly a time invariant term or risk premium $\pi^{n,1}$,

$$r_t^n = \frac{1}{n}\sum_{j=0}^{n-1} E_t r_{t+j}^1 + \pi^{n,1} \tag{1}$$

$E_t r_{t+j}^1$ being the current expectation, based on information available at time t, of the one-period interest rate prevailing in the market at time $t+j$. We work with annualized, continuously compounded rates of return, for which (1) is an exact expression. Under risk neutrality, the risk premium would be zero, although $\pi^{n,1}$ might still represent some constant term premium. The stronger version of the *EH* implies that there is no premium of any kind, long-term rates being just the average of current and expected future short-term rates, while the weaker version of the *EH* would allow for a significant constant in (1).

This expression can be generalized to consider rates of return on n- and m-period investments, n being a multiple of m,

$$r_t^n = \frac{m}{n}\sum_{j=0}^{\frac{n}{m}-1} E_t r_{t+jm}^m + \pi^{n,m} \tag{2}$$

An interesting special case occurs when $n=2m$, as in the comparison between returns on 3- and 6-month investments, or between returns on 6- and 12-month investments. Then,

$$r_t^n = \frac{1}{2}\left(r_t^m + E_t r_{t+m}^m\right) + \pi^{n,m} \tag{3}$$

so that in the case of a 3-month reference period, the rate of return on a 6-month investment should be equal to the average of the rate of return on a 3-month investment and the rate of return on a 3-month deposit expected to prevail 3 months hence, plus a possible term premium.

Under rational expectations, we have,

$$r_{t+m}^m = E_t r_{t+m}^m + \varepsilon_{t+m}^m \tag{4}$$

where ε_{t+m}^m, the rational expectations error in forecasting r_{t+m}^m at time t, has a $MA(m-1)$ structure. Finally, substituting (4) into (3) and subtracting r_t^m from both sides, we get,

$$r_t^n - r_t^m = \frac{1}{2}(r_{t+m}^m - r_t^m) - \frac{1}{2}\varepsilon_{t+m}^m + \pi^{n,m} \tag{5}$$

so that the current spread between long- and short-term interest rates (left hand side) should be a good predictor of future changes in the short-term rate (right hand side).

So long as interest rates are $I(1)$ variables, their first order difference will be stationary. But so is the rational expectations error, which has a finite order moving average structure so, unless we believe that a risk/term premium may exist which is non-stationary, (5) shows that the spread r_t^n-r_t^m will also be stationary. Hence, an implication of the *EH* is that long- and short-term interest rates in any maturity comparison for a given currency should be cointegrated, with cointegrating vector (1,-1). Cointegration between interest rates over the term structure of a currency is consistent with the idea that market forces continuously adjust to correct any temporary disequilibrium, so that risk adjusted rates of return on different maturities do not drift apart permanently, which would otherwise give rise to arbitrage opportunities.

The previous argument can be replicated for each pair of short- and long-term rates, so if the *EH* holds, there should be k-1 independent cointegrating vectors across the term structure of k rates of return. Additionally, Engsted and Tanggaard (1994) show that under the *EH*, the coefficients in each of the k-1 cointegrating vectors should add up to zero. Equivalently, the k-1 cointegrating relationships could be written as differences between interest rates at any two maturities and, in particular, between returns on successive maturities. In our sample of interest rates on 1-, 3-, 6- and 12-month deposits, the *EH* would imply the existence of 3 cointegrating vectors. Strictly speaking, we will later see that the comparison of 1- versus 3-month rates cannot be written in the form of (5) unless some assumptions are made, which might imply one cointegrating relationship less than expected.

Using different specifications for short- and long-term interest rates, Engle and Granger (1987), Stock and Watson (1988), Campbell and Shiller (1987) and Bradley and Lumpkin (1992), among many others, have, in fact, found long- and short-term *US* interest rates to be cointegrated variables $CI(1,1)$. The possible cointegration of Euro-rates has also been considered. Using daily Eurocurrency bid rates for 1-, 3-, 6- and 12-month between 1980 and 1990 for the Canadian dollar, Japanese yen, Swiss franc, British pound, and US dollar, Mougoué (1992) found evidence of a single cointegration vector among the returns offered over the term structure of each currency. With a mixture of cointegration techniques and ARIMA specifications, Chiang and Chiang (1995) used monthly data for 1977-1992 on Euro-rates at the same mentioned maturities, finding evidence of a single cointegrating vector for interest rates on the British pound and German mark interest rates, and two cointegrating vectors for interest rates on the *US* and Canadian dollars, Swiss franc and yen. They found more evidence of cointegration when they tested for stationarity of the residuals of regressions of the 1- on the 3-month rate of return, the 3- on the 6-month, and the 6- on the 12-month rate, rejecting the null hypothesis of a unit root in all cases for the currencies they considered.

We hope to confirm these results and provide additional evidence on the *EH* in a sample enlarged over time and across currencies. To that end, we use monthly averaged bid rates on one-, three-, six- and twelve-month deposits, from the London eurocurrency market, for the *US* dollar, Japanese yen, German mark, British pound, Spanish peseta, French franc, Italian lira and Swiss franc, between January 1978 and December 1996, starting somewhat later for some maturities in some currencies, in their annualized, continuous equivalent form. Figure 1 shows the time pattern of 1-month Euro-rates, clearly much more volatile during the first years of the sample, due in part to some central parity changes that took place in the European Monetary System, following periods of turbulence in the financial markets. Unit root tests (not shown here) suggest that: a) all the Euro-rates we consider are $I(1)$ variables, with the possible exception of interest rates on the italian lira, which could also be considered as stationary around a deterministic linear trend although their graphs seem to suggest otherwise, and b) there is no evidence of $I(2)$ structure in any currency or maturity[1]. So, according to our previous discussion, (1,-1) should be the cointegrating vector between any short- and long-term rate in a given term structure.

To test for cointegration over the term structure, we use the procedure proposed by Johansen (1988,1991), specifying an unrestricted *VAR* for each currency in the first differences of the rates of return on deposits at the four maturities considered. Table 1 shows that, at the 90% confidence level, there seem to be in fact three cointegrating vectors among the four interest rates considered in each currency, in full consistency with the *EH*, although the *Trace* statistic would reduce them to two in the case of the yen, peseta and Swiss franc. The possibilities of either zero or just one cointegrating relationships are strongly rejected for all currencies. Three cointegrating relationships amount to a single trend common to all the returns in a given currency. That trend could be interpreted as being the rate of inflation[2], which would determine the general level of interest rates, the term structure then determining the relationships between interest rates at different maturities. The number of cointegrating relationships turns out not to be very sensible to the number of lags chosen for the *VAR*.

To obtain Table 1 we selected the number of lags to maximize the likelihood function, provided that there would be no residual autocorrelation left. These results have also proven to be quite robust to considering the less volatile 1987-1996 sub-sample.

Our results are in line with Mougoué (1992) and Chiang and Chiang (1995), but differ from them in that we detect more evidence in favor of cointegration and hence, an even stronger evidence in favor of the *EH*. The fact that interest rate have followed stable, decreasing paths in all countries in the more recent years, which are included in our sample, may explain these differences.

Table 2 presents the three estimated cointegrating vectors for each term structure, appropriately normalized. As it is known, just the basis of the cointegrating space is identified. It is not hard to find a linear transformation to rewrite them for most currencies to approximately imply that the differences between the longest rate and any other rate is stationary or, equivalently, that the spread between interest rates at each two successive maturities is stationary. As shown by Engsted and Tanggaard (1994), these would be the implied cointegrating relationships under the *EH*. The last column in Table 2 contains, to the left, the likelihood ratio statistic to jointly test for the set of restrictions implied by the *EH*, that the matrix of coefficients in the three cointegrating relationships is,

$$\begin{bmatrix} 1 & -1 & 0 & 0 \\ 0 & 1 & -1 & 0 \\ 0 & 0 & 1 & -1 \end{bmatrix}$$

This joint hypothesis is rejected at the 99% confidence level for the yen, British pound, French franc and Italian lira, and accepted for the *US* dollar, German mark, Spanish peseta and Swiss franc. Only for the German mark and Spanish peseta is the *p*-value far from the standard significance levels. The lower volume of transactions on 12-month deposits may produce a behavior of its rate of return different from those on the shorter maturities. That suggests testing for the joint hypothesis that (1,-1) is the cointegrating vector between the 1- and 3-month interest rates, and also between the 6- and the 12-month rates. Relative to the previous test, we leave unrestricted the third cointegrating relationship. The right side of the column shows a notorious increase in *p*-values, which now lead to not rejecting the restrictions of the *EH* on the long-run relationships of the shorter term interest rates, at the 99% confidence level, except for the British pound. Rejections would also de reached for the Italian lira and the Swiss franc at the 95% confidence level, the restrictions being accepted in all the other currencies.

We also tested for non-stationarity of the differences between returns on successive maturities for a given currency, with results similar to those in Chiang and Chiang (1995). We rejected the null hypothesis of non-stationarity in all cases at the 95% confidence level, except for the 12/6-month spread on the Swiss franc. There is also some evidence of non-stationarity on the *US* dollar and British pound, again for the 6/12-month spread [see Table 3]. At the 99% confidence level, clear evidence of non-stationarity arises for the spread between the longer maturities for the Deutsche mark, British pound and Swiss franc. This maturity comparison is clearly the most problematic, since non-stationarity is rejected at the 95% confidence level for the 3/1-month spread and the 6/3-month spread for all currencies. The fact that there is more evidence of non-stationarity in the spreads between returns on the longer maturities is quite consistent with the results of Table 2 on joint tests of the restrictions implied by the *EH* on the cointegrating relationships.

Summarizing, we have found that interest rates are cointegrated over the term structure of each currency. There are 3 cointegrating relationships among the returns at the 4 maturities considered, which can be approximated as stating that differences between returns on successive maturities are stationary. In fact, at least 21 of 24 of such spreads do not seem to contain a unit root. A joint likelihood ratio test of this set of restrictions on the cointegrating relationships of returns on the shorter maturities is rejected for just one currency. Overall, these results provide quite strong preliminary evidence in favor of the *EH*. Having shown that a close connection exists among the returns offered over the term structure in each of the eight currencies considered, we now analyze a further implication of the term structure under *EH*, summarized in forward rates.

3. FORWARD RATES AS PREDICTORS OF FUTURE SPOT RATES.

With continuously compounded rates of return, implicit forward rates are defined by $(n-m)f^{n-m}_{t,t+m} = nr^n_t - mr^m_t$. Hence, with $n=2m$, we have: $f^m_{t,t+m} = 2r^n_t - r^m_t$ so that using (3) and (4),

$$r^m_{t+m} = f^m_{t,t+m} - 2\pi^{2m,m} + \varepsilon^m_{t+m} \qquad (6)$$

The *EH* of the term structure of interest rates has often been discussed by analyzing whether its implication (6) holds in a particular market. To that end,

$$r^m_{t+m} = \alpha + \beta f^m_{t,t+m} + u_{t+m} \qquad (7)$$

is usually estimated, testing the hypothesis H_0: $\alpha=0$, $\beta=1$, which is referred to as the forward rate

being an *unbiased predictor* of the future spot rate. Under the stronger version of the *EH* (incorporating neutrality) there is no risk or term premia, so H_0 should hold. In that case (4) and (6) imply that forward rates, which are known at time t, are just expectations of future short term rates: $f^m_{t,t+m} = E_t r^m_{t+m}$. A weaker version of the *EH* allows for a constant risk/term premium and suggests testing: H_0': $\beta = 1$. Under the *EH*, the error term in (7) is a rational expectations error which has a *MA(m*-1) structure as already indicated and, when significant, α will be a negative multiple of the possible risk/term premium $\pi^{2m,m}$. This analysis is specially interesting in the comparisons of 3- versus 6-month rates, and 6- versus 12-month rates, since the 3- and 6-month are some of the more actively traded maturities in most financial markets. The one-month interest rate is also of great interest, but it needs of the assumption: $E_t r_{t+1} = E_t r_{t+2}$. With that, and the definition of the 2-month forward rate: $2f^2_{t,t+1} = 3r^3_t - r^1_t$, a regression similar to (7) can be run to test unbiasedness of the 2-month forward rate, relative to the future one-month spot rate.

Hence, if the *EH* holds true, implicit forward rates should contain all relevant available information on future spot rates, which we will explore in this section, and some forecast power might be gained by exploiting such an information content, which we will analyze in Section 4. Gerlach and Smelts (1997) have estimated regressions of cumulative changes in short-term rates on current spreads, finding general evidence in favor of a unit slope, in consistency with the *EH*, although results differ widely over countries. Those regressions include, in special cases, model (7).

Figure 2 shows three-month forward rates to be apparently nonstationary, while their first order differences in Figure 3 seem to be stationary. Augmented Dickey Fuller (*ADF*) tests for the presence of a unit root in forward rates $f^2_{t,t+1}, f^3_{t,t+3}$ and $f^3_{t,t+6}$ in the eight currencies we consider (not shown to save space) provided evidence in favor of that hypothesis, at the same time the null hypothesis of two unit roots was rejected in favor of the alternative of a single root. The italian lira was no exception in this case.

Since spot and forward interest rates are $I(1)$ variables for all maturities and currencies, (7) must be interpreted as a possible cointegrating relationship between current forward and future spot rates, on which to test for the restrictions implied by the *EH*. Estimation of a cointegrating vector between two variables can be easily done in the least-squares framework initially proposed by Engle and Granger (1987). However, the resulting t-ratios do not follow a standard t-distribution, so tests on the estimated coefficients cannot be performed easily. On the other hand, the more complex maximum-likelihood estimation framework suggested by Johansen (1988, 1991), allows for a rigorous implementation of those tests. From that point of view, the latter procedure would dominate, but not much is known about the finite sample properties of the resulting estimates and test statistics in either case. Since we want to get as sharp as possible conclusions on the validity of the *EH*, we use both methods to analyze the relationship between forward and future spot interest rates.

We first present in Table 4 least-squares estimates of (7) together with *ADF* statistics to test for stationarity of the residuals. There is uniform evidence in favor of stationary residuals in all regressions so that, if there is any risk or term premium, it must be stationary, and we can think of regressions in Table 4 as being Engle and Granger (1987) estimates of a cointegrating relationship between current forward and future interest rates. Standard errors for the estimated coefficients in the Table have been computed to be robust to the possible presence of heteroskedasticity and autocorrelation, following Newey and West (1987), and they tend to increase with maturity. Slope estimates are always significant and quite close to one, except in the 1-month interest rate for the Swiss franc, although its estimated standard error is rather large. Even though the *t*-ratios do not follow a standard *t* distribution, they are favorable to the hypothesis that (1,-1) is the cointegrating vector between the two interest rates.

Since spot and forward interest rates have similar sample means, the intercept tends to be positive when the estimated slope is below one, and negative when the slope is above one. We have already mentioned that if a risk/term premium exists, the intercept in (7) will be a negative multiple of it. However, not much can be inferred from our estimates unless the intercept was individually significant, which is hard to conclude on the basis of this approximate analysis.

Even though least-squares estimates have been quite favorable to the *EH*, they provide an informal and not well justified discussion of the hypothesis. Column 2 in Table 5 contains the *Maximum eigenvalue* and *Trace* statistics to test for the number of cointegrating relationships between spot and lagged forward rates, which turns out to be one in all cases at the 10% significance level according to the maximum eigenvalue, except at the 6-month horizon for the *US* dollar, German mark, Spanish peseta, the 3-month horizon for the Swiss franc, and the 1-month returns on deposits in pesetas. There cannot be two cointegrating vectors, since both variables are $I(1)$. The maximum likelihood estimates of the single cointegrating vector are shown in Column 3, even in the cases where the test failed, together with the number of lags used in the *VAR* specification. Slope estimates are not as close to one as least-squares estimates were, most of them being above that level. Accordingly, most intercept estimates are negative.

However, a likelihood ratio test of the unit slope hypothesis (column 4 in the Table) leads to rejection in just 4 of the 24 cases at the 1% significance level, although rejection is reached in 13 cases at the 5% significance level. Rejections of this implication of the *EH* are concentrated on the 6-month horizon, which is fully consistent with the results on the joint tests reported in Table 2. In

fact, at the 5% significance level, the hypothesis is rejected for all currencies at the 6-month horizon. Rejection of the unit slope hypothesis at the 5% significance level tends to come together with a significant constant, which is specially large in absolute value in the 6-month maturity. Besides, even when the hypothesis is not rejected, negative estimates for the intercept are obtained, in all but three 1-month interest rate cases, only one of them being significant. Accepting the validity of the *EH*, our estimates would suggest the existence of constant risk/term premia for the 6- versus 12-month comparisons in all currencies but the yen, of between 45 and 146 basis points. There would be premia between 19 and 71 basis points in four currencies for the 3- versus 6-month comparisons, and even lower, between 13 and 26 basis points, just for three currencies, for the 1- versus 3-month comparisons.

However, if we impose the restrictions of the *EH*, in the form of a unit slope on forward rates and test for stationarity of the differences $r_t^m - f_{t-m,t}^m$, $m=1,3,6$, we reject the unit root hypothesis for all currencies and maturities, except maybe for the 6-month Swiss franc interest rate [last column in Table 5]. With this qualification, these tests suggest that (1,-1) may be considered to be the approximate cointegrating vector between each of the 1-, 3- and 6-month returns and the corresponding forward rate, appropriately lagged, in support of the *EH*.

To summarize the results in this Section: *a*) there is overwhelming evidence in favor of forward rates having explanatory power for future short term spot rates, *b*) unbiasedness of the forward rate is an acceptable hypothesis, except for the 6- versus 12-month comparisons, and *c*) the more general version of the *EH*, that allows for a constant term/risk premium holds in most eurocurrencies, specially at the longer maturities.

4. CAN THE TERM STRUCTURE BE USED TO FORECAST INTEREST RATES?

The results in the previous sections show that the term structure of Eurocurrencies contains significant information regarding future interest rate fluctuations, suggesting that it might be possible to exploit that information when forecasting interest rates. However, a good fit does not always come together with a good forecasting performance, and it is particularly interesting to check how the explanatory power we have documented in the forward rate translates into a good forecasting performance of spot interest rates. Evaluating the performance of the forward rate model (7) and comparing it with interest rate forecasts obtained from univariate autoregressive models in our international data set is the goal of this Section.

To check whether forward rates can be used to predict future interest rates, we estimate (7) for 1-, 3- and 6-month, with data through December 1995 and run the forecasting exercise over 1996, computing forecasting accuracy measures for the whole year, as well as for each semester. No lagged interest rate is included in this regression, which has the lagged forward rate as its only explanatory variable. For each two maturities, the predictive power of model (7) is compared with that of an autoregression in first differences of the short-term rate.

For most of the interest rates considered in our sample the restrictions imposed by a random walk model would not be rejected at standard significance levels but, trying to improve forecasts, we forced some structure, and fit an *AR*(2) model to their first differences, from which we obtained monthly univariate forecasts over 1996. In fact, the *AR*(2) model turns out to predict significantly better than a random walk model in most cases. We computed *dynamic* and *static* forecasts. The former are once and for all predictions over all 1996, obtained with data up to December 1995. They are progressively based on previous forecasts, as we run out of actual data. Static forecasts are one-month ahead predictions, in which actual data was used for the lagged explanatory variable, as needed. To obtain dynamic forecasts from (7) for the three-month interest rate, we used actual data on forward rates up to the April 1996 forecast. Starting in April, predictions of forward rates must be obtained in advance, to be used as the explanatory variable in the forecasting exercise. To that end, an *AR*(2) model was again fitted to the first difference of the forward rate in all cases. Similar strategies apply to the computation of static and dynamic forecasts of the one- and six-month rates in each currency. It must be emphasized that the forward rate is the only explanatory power in this forecasting model.

Table 6 contains the root mean square error (*RMSE*), mean absolute error (*MAE*), both in percent terms, and Theil's inequality coefficient *U* as performance measures in the static and dynamic forecasting exercises[3]. Theil's *U* falls between 0 (in case of a perfect fit) and 1 (very bad forecasting performance). The forward rate model produces one-step-ahead forecasts of 1-month interest rates better than those obtained from the own past of interest rates [left panel in Table 6.a] for the German mark, Spanish peseta, French franc and Italian lira, and does as well as the univariate model for the *US* dollar and British pound. Results are even more evident when forecasting over a longer horizon [right panel in Table 6.a] the forward rate model predicts better than the univariate model for 1-month interest rates in all currencies except the yen and the Swiss franc. Forecasting gains are even more important than in static forecasts. In most cases, all these results arise uniformly over each semester, as well as over the whole year 1996.

This good forecasting performance of the forward rate model debilitates for longer maturities.

The forward rate model performs badly in forecasting future 3- and 6-month interest rates one month in advance and does not beat the univariate model for any currency [left panels in Tables 6.b and 6.c]. On the other hand, the forward rate model beats the *ARIMA* model in once-and-for all forecasting of the 3-month interest rates over all 1996, for all currencies except the Spanish peseta and the Swiss franc [right panel in Table 6.b], but just for the Japanese yen, French franc and Italian lira for 6-month rates [right panel in Table 6.c]. However, forecasting gains at these horizons are small.

These results should be expected: we have seen the restrictions of the Expectations Hypothesis to fail often for the longer maturities, so it is not surprising that a model that incorporates such restrictions might not forecast well. It is interesting that the forward model seems to capture the global trend, doing well in dynamic forecasting, not doing so well in one-month ahead forecasting, specially for 3- and 6-month rates. Searching for the causes of this regularity looks as an interesting issue for further research. Nevertheless, the fact that forward rates can predict quite well 1-month interest rates one month in advance is quite remarkable, since it is in this case the 3-month/1-month spread which is being used by itself to forecast future 1-month rates one month in advance, without using lags of the own rate being forecasted. That this spread can forecast even better than the own past of the 1-month interest rate in some cases should be seen as strong evidence in favor of the *EH* on the shorter end of the term structure from a practical point of view, which is of fundamental relevance to the market participant, but not often documented.

5. CONCLUSIONS

We have found quite consistent evidence in favor of the Expectations Hypothesis as an adequate representation of the term structure in the market for Eurodeposits. First, working with monthly data on 1-, 3-, 6- and 12-month interest rates on deposits denominated in *US* dollar, Japanese yen, German mark, French and Swiss francs, British pound, Italian lira and Spanish peseta over the 1978-1996 period, we have found interest rates offered on a currency at a given time to be cointegrated over the term structure. Considering the four rates of return at the different horizons, we have provided evidence in favor of three cointegrating vectors in most currencies, in full support of the Expectations Hypothesis. A joint test of the set of restrictions implied by the Expectations Hypothesis gets support for them in 4 of the 8 currencies considered, or in all but one currency if we exclude the restrictions on the long-term relationships with the return on 12-month deposits. The lower volume of transactions at this maturity may explain this difference. However, at least 21 of the 24 spreads between interest rates on successive maturities seem to be stationary, as the Expectations Hypothesis would imply. The three non-stationary spreads refer to returns on 12-month deposits.

We have also shown that implicit forward rates contain explanatory power for future short term interest rates in all currencies and maturities, as the Expectations Hypothesis would suggest. We have found both rates to be generally cointegrated, and tested for a unit slope, with general support for that hypothesis. More specifically, we have found forward rates to be unbiased predictors of future rates for most currencies, except again at the 6- versus 12-month comparison. We have also detected some indication that there might be small, constant risk/term premia, specially in the longer comparisons.

Finally, we have analyzed the extent to which the appropriate forward rate can be used to forecast future short-term interest rates. We have compared such forecasts to those obtained from univariate autoregressions. Our analysis shows that, by themselves, forward rates produce better dynamic forecasts of 3- and 6-month interest rates than univariate autoregressions for some currencies, but they never beat static forecasts obtained from the univariate model. Even more strikingly, forward rates can in most cases produce static and dynamic forecasts of 1-month interest rates which are even better than those obtained from the own past of interest rates. That the information contained in forward rates can be put to that end is quite remarkable evidence in favor of the Expectations Hypothesis, at least over the shorter end of the maturity spectrum.

REFERENCES

Bradley, M.G. and Lumpkin, S.A., 1992, The treasury yield curve as a cointegrated system, *Journal of Financial and Quantitative Analysis*, 27, 449-463.

Campbell, J.Y. and Shiller, R.J., 1987, Cointegration and test of present value models", *Journal of Political Economy* 95, 1062-1088.

Campbell, J.Y. and Shiller, R.J., 1991, Yield spreads and interest rates movements: A bird's eye view, *Review of Economic Studies*, 58, 495-514.

Chiang, T.C. and Chiang, J.J., 1995, Empirical analysis of short-term Eurocurrency rates: Evidence from a transfer function error-correction model, *Journal of Economics and Business* 47, 335-351.

Engle, R.F. and Granger, C.W.J., 1987, Co-integration and error correction: representation, estimation and testing, *Econometric*, 55, 251-276.

Engsted, T. and Tangaard, C., 1994, Cointegration and the US term structure, *Journal of Banking and Finance*, 18, 167-181.

Fama, E., 1984, The information in the term structure, *Journal of Financial Economics*, 13, 509-528.

Fama, E., 1990, Term structure forecasts of interest rates, inflation and real returns, *Journal of Monetary Economics*, 25, 59-76.

Fama, E., and Bliss, R., 1987, The information in long maturity forward rates, *American Economic Review*, 77, 680-692.

Gerlach, S. and Smets, F., 1997, The term structure of Euro-rates: some evidence in support of the expectations hypothesis, *The Journal of International Money and Finance*, 16, 305-323.

Hardouvelis, G., 1994, The term structure spread and future changes in long and short rates in the G7 countries, *Journal of Monetary Economics*, 25, 59-76.

Johansen, S., 1988, Statistical analysis of cointegrated vectors, *Journal of Economic Dynamics and Control*, 12, 231-254.

Johansen, S., 1991, Estimation and hypothesis testing of cointegration vectors in gaussian vector autoregressive models, *Econometrica*, 59, 1551-1580.

Jorion, P. and Mishkin, F., 1991, A multicountry comparison of term-structure forecasts at long horizons, *Journal of Financial Economics*, 29, 59-80.

Mankiw, N. and Miron, J.A., 1986, The changing behavior of the term structure of interest rates, *The Quarterly Journal of Economics*, 101, 211-228.

Mankiw, N. and Summers, L.H., 1984, Do long term rates overreact to short-term interest rates?, *Brookings Papers on Economic Activity*, 1, 223-242.

Mishkin, F. 1988. The information in the term structure: Some further results. *Journal of Applied Econometrics*, 3, 307-314.

Mougoué, M., 1992, The term structure of interest rates as a cointegrating system: empirical evidence from the eurocurrency market, *The Journal of Financial Research*, XV, 3, 285-296.

Newey, W., and West, K., A simple, positive semi-definite, heteroscedasticity and autocorrelation consistent covariance matrix, *Econometrica*, 55, 703-708.

Osterwald-Lenum, M., 1992, A note with fractiles of the asymptotic distribution of the maximum likelihood cointegration rank test statistics: four cases, *Oxford Bulletin of Economics and Statistics*, 54, 461-472.

Shiller, R.J., Campbell, J.Y., and Schoenholtz, K.L., 1983, Forward rates and future policy: interpreting the term structure of interest rates, *Brookings Papers on Economic Activity*, 1, 173-217.

Shiller, R.J., 1990, The term structure of interest rates, in B.Friedman and F.Hahn (eds.), *Handbook of Monetary Economics*, North-Holland, Amsterdam.

Stock, J.M. and Watson, M., 1988, Testing for common trends, *Journal of the American Statistical Association*, 1097-1107.

Table 1

Cointegration tests among 1-, 3-, 6- 12-month interest rates in each currency

Hypothesized number of cointegrating relationships	*Maximum Eigenvalue and Trace statistics for existence of k-cointegrating relationships over a currency term structure*[a]								90% *Critical values*[c]	
	US[b] *1978/96*	*Yen* *1979/96*	*GM* *1978/96*	*BP* *1979/96*	*SP* *1985/96*	*FF* *1979/96*	*LI* *1979/96*	*SF* *1983/96*		
n[d]	4	4	4	4	4	4	4	1	λ_{max}	*Trace*
None	52.1*/113.8*	69.3*/105.5*	44.7*/85.6*	40.4*/86.1*	38.0*/77.5*	69.0*/122.2*	84.7*/155.1*	110.3*/155.5*	18.0	49.9
At most 1	39.0*/61.7*	23.0*/36.2*	21.7*/40.9*	24.5*/45.8*	22.5*/39.5*	33.7*/53.3*	51.2*/70.4*	32.0*/45.2*	14.1	31.9
At most 2	20.4*/22.7*	11.7*/13.2	14.1*/19.3*	18.4*/21.3*	13.8*/17.1	18.8*/19.5*	18.4*/19.3*	12.4*/13.3	10.3	17.8
At most 3	2.3/2.3	1.5/1.5	5.2/5.2	2.9/2.9	3.2/3.2	0.7/0.7	0.9/0.9	0.9/0.9	7.5	7.5

Notes:
a) *Maximum eigenvalue* (left) and *Trace* statistics (right), as defined in Johansen (1988). An asterisk denotes significance at the 90% confidence level.
b) *US, Yen, GM, BP, SP, FF, LI,* and *SF* denote the *US* dollar, Japanese yen, German mark, British pound, Spanish peseta, French franc, Italian lira and Swiss franc, respectively.
c) Critical values for testing for the presence of *k* cointegrating relationships, at the 90% confidence level.
d) *n* denotes the number of lags used in the test. A constant was always included in the cointegrating vectors, but not in the estimated *VAR* in first differences. No trend was included in either one.

Table 2

Normalized maximum-likelihood estimates of the cointegrating vectors within each term structure[a]

	Estimated coefficients on interest rates[b]					*LRT[c]*	
	1-month	*3-month*	*6-month*	*12-month*	*Constant*	*On 3 cr*	*On 2 cr*
US	1.0	-2.160	1.469	-0.330	0.148		
	-0.955	1.0	-0.068	0.026	-0.103	12.66	1.86
	-1.012	1.221	1.0	-1.347	0.960	(0.01)	(0.39)
Yen	1.0	-0.823	-0.905	0.778	-0.148		
	-0.788	1.0	1.801	-2.126	0.292	24.71	0.82
	0.125	-0.385	1.0	-0.772	0.161	(0.00)	(0.66)
GM	1.0	-2.228	1.509	-0.281	0.033		
	-0.003	1.0	-1.481	0.487	0.018	5.65	4.28
	0.049	-0.526	1.0	-0.544	0.095	(0.13)	(0.12)
BP	1.0	-2.187	1.666	-0.516	0.357		
	-0.260	1.0	-0.924	0.178	0.024	19.22	11.23
	-0.048	-0.402	1.0	-0.586	0.267	(0.00)	(0.00)
SP	1.0	-3.343	3.647	-1.298	0.030		
	-0.348	-0.067	1.0	-0.597	0.080	2.95	4.23
	-1.060	2.555	1.0	-2.809	2.725	(0.23)	(0.24)
FF	1.0	-0.326	-1.527	0.957	-0.572		
	-0.373	1.0	-0.495	-0.124	-0.133	17.08	4.67
	0.088	-0.608	1.0	-0.542	0.397	(0.00)	(0.10)
LI	0.132	-0.732	1.0	-0.417	0.150		
	-0.726	1.0	-0.377	0.092	0.135	30.19	6.98
	-0.552	1.0	0.037	-0.544	0.523	(0.00)	(0.03)
SF	1.0	-2.610	2.211	-0.625	0.134		
	0.060	1.0	-1.781	0.739	-0.009	12.57	7.42
	0.006	0.149	1.0	-1.245	0.302	(0.01)	(0.02)

Note:
a) For mnemonics, see Table 1.
b) Each row gives the coefficients of one of the cointegrating vectors.
c) *Likelihood Ratio statistic* to test the restrictions that the *EH* imposes on the cointegrating space. *p*-values are shown in brackets.

Table 3

Augmented Dickey-Fuller/Phillips-Perron statistics for stationarity of differences between successive interest rates

	$r_t^3 - r_t^1$	$r_t^6 - r_t^3$	$r_t^{12} - r_t^6$
US	-4.07** (6) / -7.20**	-8.75** (0) / -7.92**	-3.05 (6) *c,t* / -4.48**
Yen	-4.83** (6) *c,t* / -9.20**	-5.14**(6) *c,t*/ -7.07**	-4.53** (4) *c,t* / -4.26**
GM	-4.55** (2) *c,t* / -8.30**	-4.39** (0) / -4.12**	-2.16* (0) / -2.55*
BP	-10.14** (0) *c* / -10.51**	-3.46** (2) *c* / -3.73**	-2.00* (1) / -1.67
SP	-5.61** (2) / -7.38**	-3.52** (3) *c* / -8.12**	-4.25** (0) *c* / -4.10**
FF	-14.97** (0) / -15.02**	-6.03** (4) *c,t* / -6.53**	-4.37** (4) *c,t* / -4.35**
LI	-12.51** (0) *c,t* / -12.38**	-6.29** (3) *c* / -6.69**	-6.37** (1) *c,t* / -4.53**
SF	-4.44** (4) / -6.28**	-2.28* (4) / -3.42**	-1.90 (0) / -1.53

Note: *Augmented Dickey-Fuller* (left) and *Phillips-Perron* (right) statistics for testing the null hypothesis of a unit root in the spreads. The number of lags used in the model in first differences of the spread is shown in brackets. The same model is used for both tests. A possible constant or trend in that model are indicated by *c* and *t*. Critical values when no constant or trend are included are -1.62, -1.94, -2.57 at the 90%, 95% and 99% confidence levels, respectively, for both tests. If a constant is included, critical values are -2.57, -2.87 and -3.46, for both tests. If a constant and a trend are included, critical values are -3.14, -3.43 and -4.00, for both tests. An (two) asterisk denotes rejection of non-stationarity at the 95% (99%) confidence level.

Table 4
Estimated regression

$$r_t^m = \alpha + \beta f_{t-m,t}^m + u_t\,, \qquad m = 1,3,6$$

	Maturity	Parameter estimates α^a	β^a	ADF^b	R^2
US	1 m.	-0.021 (0.232)	0.987 (0.034)	-6.35(2)	0.95
	3 m.	0.292 (0.494)	0.947 (0.069)	-6.01(4)	0.83
	6 m.	-0.306 (0.663)	1.056 (0.096)	-5.04(3)	0.69
Yen	1 m.	-0.036 (0.105)	0.979 (0.018)	-13.70(0)	0.95
	3 m.	-0.233 (0.196)	1.084 (0.059)	-3.46(3)	0.78
	6 m.	-0.192 (0.268)	1.042 (0.052)	-3.93(4)	0.81
GM	1 m.	-0.075 (0.083)	1.001 (0.014)	-6.35(2)	0.98
	3 m.	0.123 (0.234)	0.983 (0.040)	-5.07(4)	0.91
	6 m.	0.582 (0.461)	0.937 (0.077)	-5.20(4)	0.73
BP	1 m.	-0.272 (0.132)	1.034 (0.011)	-10.12(0)	0.97
	3 m.	-0.060 (0.324)	1.027 (0.035)	-5.82(4)	0.89
	6 m.	-0.238 (0.638)	1.071 (0.070)	-5.83(4)	0.74
SP	1 m.	0.897 (0.699)	0.922 (0.062)	-11.32(0)	0.79
	3 m.	0.018 (0.987)	1.033 (0.090)	-5.13(4)	0.76
	6 m.	-1.669 (1.235)	1.208 (0.117)	-5.19(4)	0.61
FF	1 m.	-0.625 (0.663)	1.038 (0.072)	-7.78(4)	0.81
	3 m.	0.708 (0.543)	0.916 (0.064)	-7.93(1)	0.78
	6 m.	-0.886 (0.708)	1.164 (0.087)	-5.30(1)	0.78
Li	1 m.	0.486 (0.553)	0.960 (0.047)	-8.97(4)	0.87
	3 m.	0.619 (0.776)	0.965 (0.068)	-6.61(3)	0.76
	6 m.	-0.803 (0.893)	1.107 (0.080)	-5.83(1)	0.76
SF	1 m.	1.433 (0.951)	0.622 (0.217)	-5.04(0)	0.48
	3 m.	0.043 (0.264)	0.994 (0.050)	-4.63(3)	0.77
	6 m.	0.451 (0.493)	0.951 (0.096)	-4.35(1)	0.67

Note: (a) Numbers in brackets are standard errors robust to heteroskedasticity and autocorrelation.
(b) *Augmented Dickey-Fuller* tests for stationarity of the residuals. No constant or trend were included in the model in first differences of the residuals. Critical values at the 1%, 5% and 10% significance level are -3.96, -3.41 and -3.13, respectively. The number of lags used is shown in brackets.

Table 5
Estimated cointegrating relationship:

$$r_t^m = \alpha + \beta f_{t-m,t}^m + u_t\,, \qquad m = 1,3,6$$

	Maturity	$\lambda_{max}/Trace^a$	Parameter estimates α^b	β^b	n^c	H_0: $\beta=1^d$	ADF and Phillips-Perron statistics[e]: $r_t^m - f_{t-m,t}^m$
US	1 m.	37.3 / 39.5	-0.137 (0.117)	1.002 (0.013)	4	0.01 (0.94)	-6.3(6) / -8.7
	3 m.	31.8 / 34.3	-0.343 (0.224)	1.026 (0.024)	4	0.73 (0.38)	-5.5(3) / -6.1
	6 m.	13.2 / 16.8	-2.922 (0.729)	1.386 (0.085)	12	6.08 (0.01)	-3.1(6) / -4.1
Yen	1 m.	17.8 / 20.1	0.234 (0.097)	0.937 (0.016)	12	8.14 (0.00)	-6.8(6) / -11.8
	3 m.	56.4 / 63.7	-0.172 (0.283)	1.050 (0.050)	12	0.14 (0.71)	-3.9(6) / -4.3
	6 m.	21.9 / 24.6	-0.318 (0.179)	1.086 (0.032)	12	4.19 (0.04)	-2.9(6) / -3.9
GM	1 m.	27.1 / 32.0	-0.194 (0.089)	1.019 (0.013)	4	2.01 (0.16)	-6.3(2) / -11.4
	3 m.	23.1 / 28.3	-0.384 (0.183)	1.060 (0.026)	4	3.65 (0.06)	-4.3(6) / -4.5
	6 m.	10.6 / 17.0	-1.671 (0.691)	1.286 (0.105)	12	4.01 (0.05)	-2.8(6) / -4.4
BP	1 m.	16.8 / 19.9	-0.387 (0.173)	1.043 (0.015)	12	5.22 (0.02)	-10.1(0) / -9.4
	3 m.	16.4 / 24.8	-0.512 (0.243)	1.073 (0.023)	12	4.04 (0.04)	-3.8(6) / -4.6
	6 m.	18.1 / 23.7	-2.018 (0.426)	1.265 (0.042)	8	8.19 (0.00)	-3.2(6) / -4.2
SP	1 m.	12.9 / 17.4	0.173 (0.483)	0.987 (0.035)	12	0.47 (0.49)	-6.2(3) / -11.7
	3 m.	25.6 / 28.3	-1.421 (0.594)	1.162 (0.045)	12	7.24 (0.01)	-4.2(3) / -6.3
	6 m.	14.3 / 17.2	-1.728 (0.500)	1.199 (0.045)	12	5.84 (0.02)	-4.3(1) / -3.3
FF	1 m.	38.1 / 38.9	-0.330 (0.373)	1.016 (0.032)	8	0.50 (0.48)	-7.8(3) / -13.7
	3 m.	27.5 / 29.1	-0.688 (0.458)	0.932 (0.039)	8	3.11 (0.08)	-8.0(1) / -5.3
	6 m.	37.9 / 39.5	-1.403 (0.656)	1.231 (0.062)	4	6.88 (0.01)	-2.9(6) / -3.7
Li	1 m.	55.2 / 56.8	0.279 (0.218)	0.977 (0.015)	4	2.10 (0.15)	-9.6(3) / 10.5
	3 m.	66.3 / 67.4	-0.478 (0.342)	1.053 (0.024)	4	5.33 (0.02)	-6.8(3) / -4.4
	6 m.	59.0 / 60.5	-1.672 (0.523)	1.185 (0.039)	4	8.62 (0.00)	-6.2(1) / -4.0
SF	1 m.	17.0 / 21.9	-0.322 (0.153)	1.042 (0.028)	8	0.52 (0.47)	-5.0(3) / -4.8
	3 m.	12.7 / 16.1	-0.467 (0.144)	1.095 (0.026)	8	5.14 (0.02)	-4.7(3) / -4.1
	6 m.	75.9 / 78.5	-0.913 (0.263)	1.238 (0.051)	8	11.56 (0.00)	-2.2(6) / -4.1

Note: (a) *Maximum eigenvalue* and *Trace* statistics. Their critical values when testing the existence of *at most one cointegrating relationship*, at the 10%, 5% and 1% significance levels, are 13.8, 15.7 and 20.2 for the *Maximum eigenvalue*, and 17.8, 20.0 and 24.7, for the *Trace* statistic (Osterwald-Lenum (1992)).
(b) Numbers in brackets are maximum-likelihood standard errors.
(c) Number of lags used in the *VAR* in first differences.
(d) *Likelihood ratio* statistic to test the null hypothesis that the cointegrating vector is (1,-1).
(e) *ADF* and *Phillips-Perron* statistics for presence of a unit root in the difference between future rates and current forward rates. Number of lags for *ADF* in brackets. We allowed for a constant in the model. Critical values for both tests under this specification at the 10%, 5% and 1% significance levels are -1.62, -1.94 and -2.57.

Table 6.b

3-month interest rates

		STATIC FORECASTS									DYNAMIC FORECASTS								
		1st semester 1996			2nd semester 1996			1996			1st semester 1996			2nd semester 1996			1996		
		RMSE	MAE	U	RMSE	MAE	U	RMSE	MAE	U	RMSE	MAE	U	RMSE	MAE	U	RMSE	MAE	U
US	Univariate	0.025	0.020	0.012	0.018	0.016	0.009	0.022	0.018	0.011	0.053	0.049	0.025	0.024	0.022	0.012	0.041	0.035	0.020
	Forward	0.048	0.042	0.024	0.051	0.045	0.025	0.049	0.043	0.024	0.029	0.025	0.014	0.039	0.039	0.020	0.035	0.032	0.017
Yen	Univariate	0.098	0.076	0.049	0.113	0.092	0.062	0.106	0.084	0.056	0.294	0.288	0.175	0.313	0.306	0.198	0.304	0.297	0.186
	Forward	0.236	0.200	0.115	0.648	0.613	0.239	0.489	0.406	0.195	0.203	0.197	0.114	0.313	0.310	0.192	0.263	0.253	0.152
GM	Univariate	0.040	0.032	0.021	0.025	0.021	0.012	0.034	0.027	0.017	0.142	0.139	0.065	0.196	0.194	0.089	0.171	0.166	0.078
	Forward	0.090	0.068	0.044	0.057	0.048	0.028	0.076	0.058	0.038	0.104	0.098	0.049	0.115	0.112	0.054	0.110	0.105	0.052
BP	Univariate	0.018	0.015	0.009	0.024	0.018	0.012	0.021	0.015	0.011	0.057	0.051	0.027	0.079	0.065	0.037	0.069	0.058	0.032
	Forward	0.044	0.039	0.022	0.060	0.057	0.030	0.053	0.048	0.026	0.042	0.038	0.021	0.048	0.044	0.024	0.045	0.041	0.023
SP	Univariate	0.049	0.041	0.023	0.027	0.023	0.013	0.040	0.032	0.020	0.141	0.122	0.062	0.246	0.241	0.108	0.200	0.182	0.086
	Forward	0.122	0.120	0.056	0.071	0.063	0.033	0.100	0.091	0.048	0.169	0.158	0.075	0.275	0.271	0.119	0.228	0.215	0.097
FF	Univariate	0.098	0.071	0.051	0.040	0.035	0.020	0.075	0.053	0.041	0.360	0.351	0.149	0.513	0.508	0.202	0.443	0.429	0.176
	Forward	0.218	0.197	0.105	0.102	0.090	0.047	0.171	0.143	0.086	0.309	0.305	0.134	0.427	0.421	0.173	0.372	0.362	0.153
LI	Univariate	0.037	0.027	0.018	0.037	0.029	0.017	0.037	0.028	0.018	0.129	0.114	0.058	0.319	0.303	0.133	0.243	0.208	0.100
	Forward	0.059	0.054	0.029	0.081	0.066	0.037	0.071	0.060	0.032	0.114	0.101	0.052	0.293	0.277	0.123	0.223	0.189	0.092
SF	Univariate	0.108	0.086	0.060	0.129	0.111	0.060	0.119	0.099	0.060	0.152	0.143	0.080	0.149	0.120	0.077	0.150	0.131	0.078
	Forward	0.215	0.195	0.121	0.313	0.264	0.140	0.269	0.230	0.132	0.179	0.164	0.092	0.147	0.117	0.080	0.163	0.140	0.086

Table 6.a
1-month interest rates

		STATIC FORECASTS									DYNAMIC FORECASTS								
		1st semester 1996			2nd semester 1996			1996			1st semester 1996			2nd semester 1996			1996		
		RMSE	MAE	U	RMSE	MAE	U	RMSE	MAE	U	RMSE	MAE	U	RMSE	MAE	U	RMSE	MAE	U
US	Univariate	0.026	0.020	0.013	0.018	0.014	0.009	0.022	0.017	0.011	0.078	0.076	0.037	0.068	0.066	0.033	0.073	0.071	0.035
	Forward	0.025	0.020	0.012	0.023	0.019	0.012	0.024	0.020	0.012	0.022	0.019	0.011	0.016	0.015	0.008	0.019	0.017	0.009
Yen	Univariate	0.113	0.097	0.063	0.057	0.047	0.027	0.090	0.072	0.050	0.205	0.190	0.122	0.164	0.160	0.091	0.185	0.175	0.109
	Forward	0.139	0.105	0.063	0.253	0.186	0.116	0.204	0.145	0.092	0.218	0.201	0.130	0.226	0.214	0.122	0.217	0.208	0.127
GM	Univariate	0.055	0.037	0.028	0.031	0.026	0.015	0.045	0.031	0.023	0.204	0.200	0.092	0.290	0.287	0.126	0.251	0.244	0.110
	Forward	0.043	0.036	0.022	0.027	0.025	0.014	0.036	0.030	0.018	0.064	0.059	0.031	0.130	0.125	0.060	0.102	0.092	0.047
BP	Univariate	0.022	0.019	0.011	0.016	0.011	0.008	0.020	0.015	0.010	0.075	0.068	0.036	0.107	0.103	0.050	0.093	0.085	0.043
	Forward	0.014	0.013	0.007	0.027	0.024	0.014	0.021	0.018	0.011	0.040	0.033	0.019	0.063	0.057	0.030	0.053	0.045	0.025
SP	Univariate	0.055	0.047	0.026	0.030	0.022	0.014	0.044	0.035	0.022	0.135	0.112	0.059	0.243	0.239	0.107	0.197	0.175	0.084
	Forward	0.033	0.029	0.017	0.028	0.023	0.015	0.031	0.026	0.016	0.106	0.082	0.047	0.198	0.193	0.088	0.159	0.138	0.069
FF	Univariate	0.144	0.115	0.073	0.032	0.028	0.016	0.105	0.072	0.057	0.397	0.390	0.163	0.551	0.548	0.215	0.480	0.469	0.188
	Forward	0.085	0.075	0.043	0.103	0.094	0.054	0.094	0.084	0.047	0.296	0.281	0.126	0.449	0.446	0.182	0.380	0.363	0.154
LI	Univariate	0.036	0.030	0.017	0.041	0.034	0.020	0.039	0.032	0.018	0.110	0.098	0.051	0.291	0.279	0.124	0.221	0.189	0.092
	Forward	0.023	0.018	0.011	0.036	0.034	0.018	0.030	0.026	0.014	0.101	0.087	0.046	0.278	0.265	0.118	0.209	0.176	0.087
SF	Univariate	0.170	0.150	0.08998	0.194	0.167	0.086	0.182	0.159	0.087	0.236	0.209	0.099	0.251	0.199	0.099	0.243	0.204	0.099
	Forward	0.422	0.381	0.140	0.493	0.456	0.076	0.459	0.418	0.110	0.444	0.390	0.150	0.421	0.357	0.154	0.433	0.374	0.153

Note: Root Mean Square Error (*RMSE*), Mean Absolute Error (*MAE*) and Theil's *U* statistics for static and dynamic forecasts obtained from *AR*(3) univariate autoregressions, as well as from a regression of the interest rate on the corresponding forward rate, appropriately lagged.

Table 6.c

6-month interest rates

		STATIC FORECASTS									DYNAMIC FORECASTS								
		1st semester 1996			*2nd semester 1996*			*1996*			*1st semester 1996*			*2nd semester 1996*			*1996*		
		RMSE	*MAE*	*U*	*RMSE*	*MAE*	*U*	*RMSE*	*MAE*	*U*	*RMSE*	*MAE*	*U*	*RMSE*	*MAE*	*U*	*RMSE*	*MAE*	*U*
US	*Univariate*	0.031	0.028	0.016	0.023	0.020	0.012	0.028	0.024	0.014	0.040	0.031	0.019	0.035	0.031	0.018	0.038	0.031	0.019
	Forward	0.083	0.070	0.039	0.112	0.103	0.055	0.096	0.086	0.048	0.082	0.070	0.039	0.056	0.054	0.029	0.071	0.062	0.035
Yen	*Univariate*	0.127	0.101	0.062	0.131	0.106	0.072	0.129	0.104	0.067	0.426	0.411	0.279	0.540	0.540	0.380	0.487	0.475	0.323
	Forward	0.322	0.276	0.147	1.091	0.942	0.332	0.804	0.609	0.271	0.322	0.276	0.147	0.162	0.127	0.108	0.255	0.201	0.133
GM	*Univariate*	0.051	0.038	0.018	0.020	0.018	0.011	0.039	0.028	0.015	0.111	0.109	0.052	0.152	0.148	0.070	0.133	0.128	0.062
	Forward	0.270	0.252	0.120	0.110	0.094	0.052	0.206	0.173	0.096	0.270	0.252	0.120	0.126	0.122	0.059	0.210	0.187	0.097
BP	*Univariate*	0.018	0.014	0.009	0.031	0.024	0.016	0.025	0.019	0.013	0.019	0.016	0.009	0.057	0.050	0.030	0.042	0.033	0.022
	Forward	0.147	0.138	0.069	0.086	0.075	0.040	0.121	0.107	0.057	0.147	0.138	0.069	0.062	0.059	0.031	0.113	0.098	0.055
SP	*Univariate*	0.046	0.034	0.022	0.032	0.027	0.015	0.039	0.031	0.019	0.143	0.125	0.063	0.261	0.254	0.113	0.210	0.190	0.089
	Forward	0.253	0.249	0.111	0.160	0.157	0.075	0.212	0.203	0.098	0.253	0.249	0.111	0.315	0.308	0.134	0.286	0.279	0.121
FF	*Univariate*	0.086	0.062	0.045	0.045	0.040	0.022	0.069	0.051	0.037	0.324	0.315	0.137	0.485	0.478	0.192	0.413	0.397	0.165
	Forward	0.386	0.379	0.160	0.206	0.199	0.092	0.310	0.289	0.137	0.386	0.379	0.160	0.393	0.386	0.162	0.390	0.383	0.161
LI	*Univariate*	0.040	0.032	0.019	0.038	0.032	0.018	0.038	0.032	0.019	0.144	0.129	0.065	0.346	0.327	0.141	0.265	0.228	0.107
	Forward	0.158	0.151	0.072	0.127	0.124	0.058	0.144	0.138	0.066	0.158	0.151	0.072	0.321	0.301	0.132	0.253	0.226	0.103
SF	*Univariate*	0.099	0.082	0.056	0.126	0.111	0.058	0.113	0.096	0.057	0.146	0.116	0.092	0.183	0.161	0.114	0.165	0.138	0.103
	Forward	0.582	0.495	0.225	0.281	0.243	0.137	0.457	0.369	0.187	0.582	0.495	0.225	0.174	0.153	0.108	0.430	0.324	0.183

1. As noted by Mougoué (1992), these results imply that either the real rate of interest, the rate of inflation or the risk/term premium are non-stationary.

2. Prices seem to be integrated process of order two in most international empirical studies.

3. $$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{r_t - \hat{r}_t}{r_t}\right)^2}\ , \quad MAE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left|\frac{r_t - \hat{r}_t}{r_t}\right|}\ , \quad U = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(r_t - \hat{r}_t)^2}}{\sqrt{\frac{1}{n}\sum_{i=1}^{n} r_t^2} + \sqrt{\frac{1}{n}\sum_{i=1}^{n} \hat{r}_t^2}}$$

Figure 1

ONE MONTH EURO-RATES

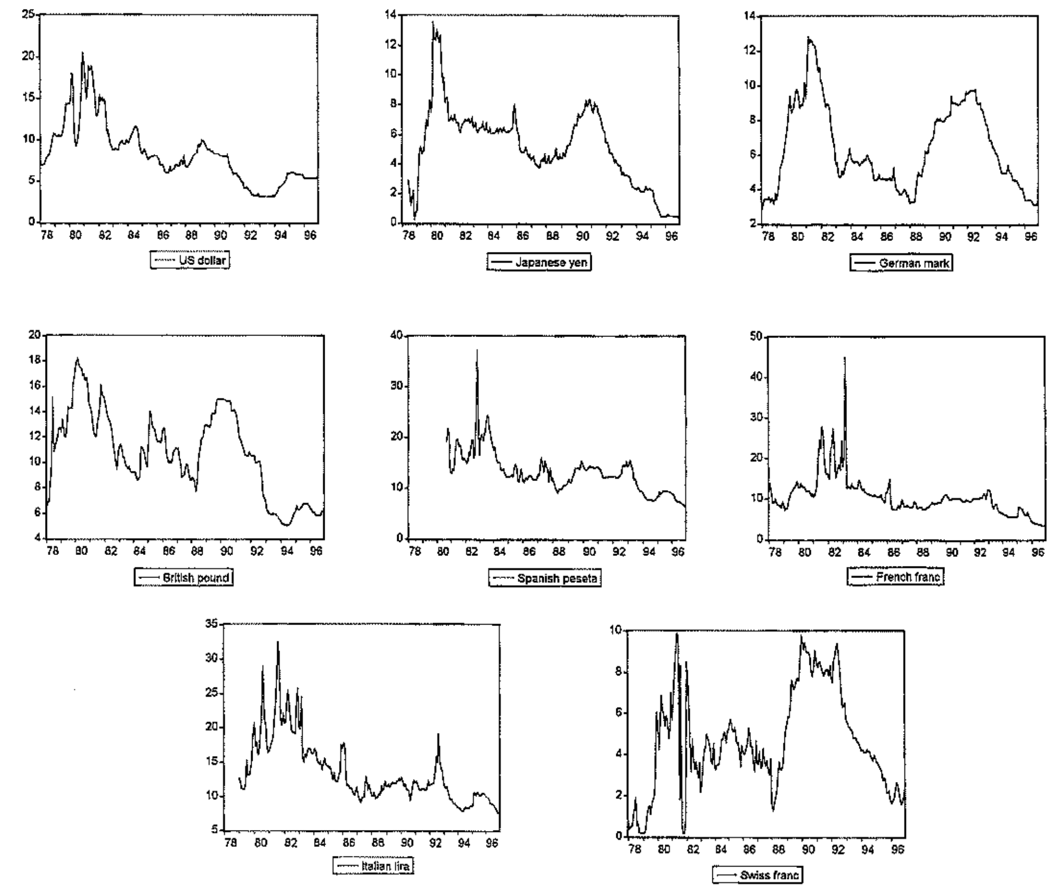

Figure 2

3-MONTH FORWARD RATES

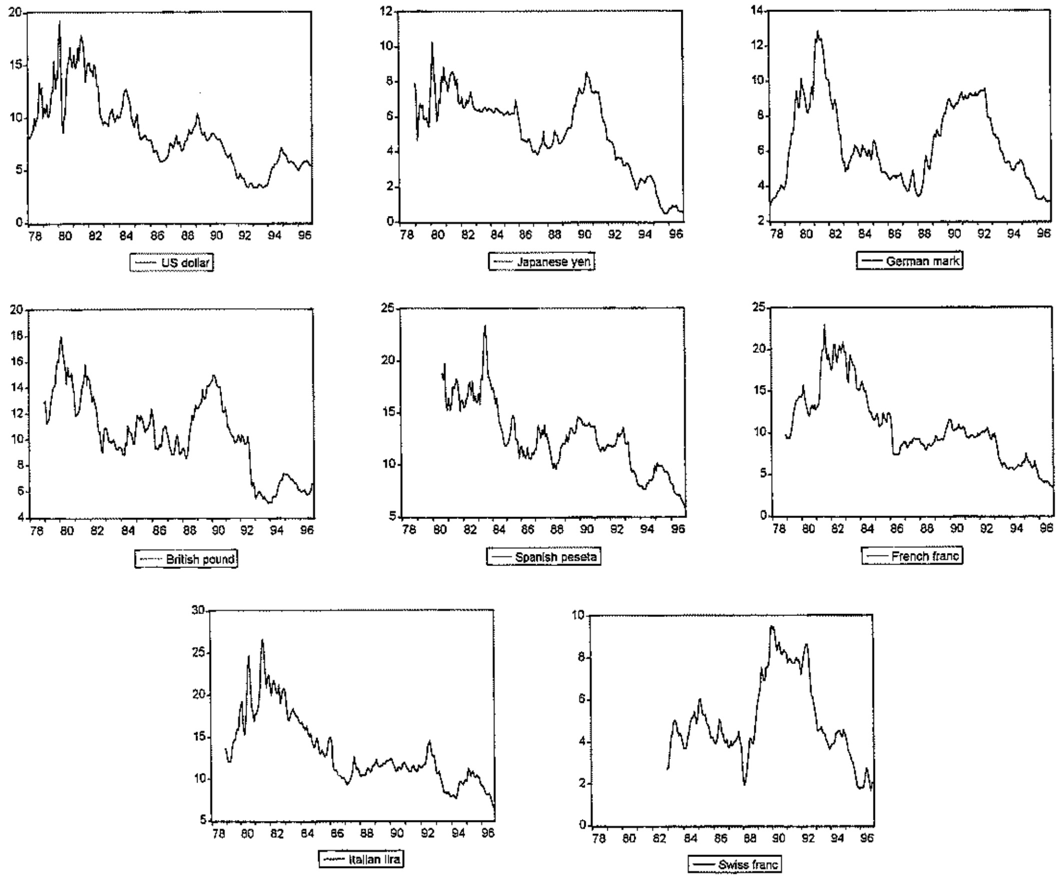

Figure 3

FIRST DIFFERENCES OF 3-MONTH FORWARD RATES